इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

“जानने का अधिकार, जीने का अधिकार”
Mazdoor Kisan Shakti Sangathan
“The Right to Information, The Right to Live”

“पुराने को छोड नये के तरफ”
Jawaharlal Nehru
“Step Out From the Old to the New”

IS 14256 (1995): Rating specification for semiconductor power converters for adjustable speed electric drive systems - particularly for DC motor drives [ETD 31: Power Electronics]

“ज्ञान से एक नये भारत का निर्माण”
Satyanarayan Gangaram Pitroda
“Invent a New India Using Knowledge”

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

“ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है”
Bhartṛhari—Nītiśatakam
“Knowledge is such a treasure which cannot be stolen”

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

PROTECTED BY COPYRIGHT

IS 14256 : 1995
(Reaffirmed 2005)

भारतीय मानक

समायोज्य गति विद्युत चालन तंत्र के अर्धचालक पावर परिवर्तकों की रेटिंग विशिष्टि — विशेषकर डी. सी. मोटर चालकों के लिए

Indian Standard

RATING SPECIFICATION FOR SEMICONDUCTOR POWER CONVERTERS FOR ADJUSTABLE SPEED ELECTRIC DRIVE SYSTEMS — PARTICULARLY FOR DC MOTOR DRIVES

UDC 621 : 3·02·523 : 621·382 ; 621·314·5

© BIS 1995

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

December 1995 Price Group 9

Power Electronics Sectional Committee, ETD 31

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Power Electronics Sectional Committee had been approved by the Electrotechnical Division Council.

This standard gives the methods for specifying ratings, particularly for dc motor drives. This standard is aligned with IEC 1136-1 (1992) 'Semiconductor power converters — General application requirements for adjustable speed electric drive systems: Part 1 Rating specifications, particularly for dc motor drives'.

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it should be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

RATING SPECIFICATION FOR SEMICONDUCTOR POWER CONVERTERS FOR ADJUSTABLE SPEED ELECTRIC DRIVE SYSTEMS — PARTICULARLY FOR DC MOTOR DRIVES

1 GENERAL

1.1 Scope

This standard provides methods for specifying ratings for semiconductor power converters for adjustable speed electric drive systems, particularly for dc motor drives.

It has been established with respect to, but is not restricted to converters of the line- or machine-commutated type. It is not intended to cover adjustable speed drives for traction purposes.

The term semiconductor, as used in this document, principally means reverse blocking triode thyristor. When applicable, the standard applies also to converters with other types of semiconductor devices (for example, bi-directional thyristors).

2 REFERENCE

2.1 The following Indian Standard is a necessary adjunct to this standard:

IS No.	*Title*
1885 (Part 27) : 1985	Electrotechnical vocabulary : Part 27 Power electronics (*first revision*)

3 DEFINITIONS

3.1 For the purpose of this standard, following definitions in addition to those in IS 1885 (Part 27) : 1985 shall apply.

3.1.1 *Semiconductor Converter Equipment (Thyristor Converter Unit or Thyristor Converter)*

Functional unit for power conversion comprising one or more semiconductor assemblies together with converter transformer, essential switching devices and other auxiliary equipment, if any. It may include the gating equipment.

3.2 Classification of Semiconductor Converters

The following designations are intended to describe the functional characteristics of converters, but not necessarily the circuits or components used.

NOTE — The figures refer only to the converters. Rotational direction of motors may be changed by field or armature reversal.

3.3 Reversible Converter

Converter in which the flow of dc power is reversible.

3.4 Non-reversible Converter

Converter in which the flow of dc power is not reversible.

3.5 Semi-Converter

Non-reversible converter for connection to a dc circuit in which there is only one possible voltage polarity and current direction (*see* Fig. 1).

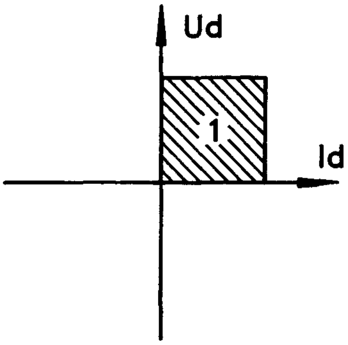

FIG. 1 SEMI-CONVERTER IN WHICH THE DIRECT CURRENT CAN FLOW IN ONE DIRECTION ONLY AND WHICH IS NOT CAPABLE OF RETURNING ENERGY FROM THE LOAD TO THE ALTERNATING CURRENT SUPPLY. THIS FORM OF CONVERTER OPERATES IN QUADRANT 1 ONLY

NOTE — Quadrant 1 implies motoring torque in the agreed forward direction of motor rotation.

3.6 Single Converter

Reversible converter which is connected to a dc circuit such that the direct current supplied by the converter can only flow in one direction (*see* Fig. 2).

3.7 Double Converter

Reversile converter connected to a dc circuit such that energy can be accepted from or returned to the ac supply system and the direct current supplied by the converter can flow in either direction (*see* Fig. 3).

A double converter usually consists of two sections, one for each direction of current flow.

NOTE — The converter sections may be supplied from common windings, from separate windings on a common transformer, or from separate transformers.

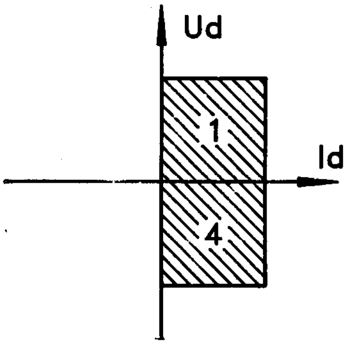

FIG. 2 SINGLE CONVERTER IN WHICH THE DIRECT CURRENT CAN FLOW IN ONE DIRECTION ONLY AND WHICH IS CAPABLE OF RETURNING ENERGY FROM THE LOAD TO THE ALTERNATING CURRENT SUPPLY. THIS FORM OF CONVERTER OPERATES IN QUADRANTS 1 AND 4

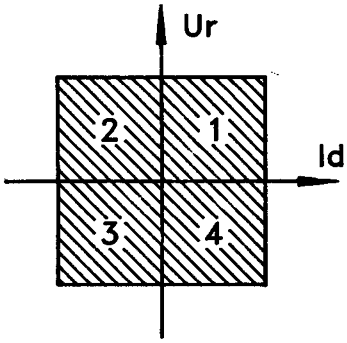

FIG. 3 DOUBLE CONVERTER IN WHICH THE DIRECT CURRENT CAN FLOW IN EITHER DIRECTION ONLY AND WHICH IS CAPABLE OF RETURNING ENERGY FROM THE LOAD TO THE ALTERNATING CURRENT SUPPLY. THIS FORM OF CONVERTER OPERATES IN QUADRANTS 1, 2, 3 AND 4

3.8 Semiconductor Converter Section

Those parts of a semiconductor converter unit, containing the power semiconductors together with their auxiliaries (including individual fuses, individual transformers or windings and individual circulating current reactors, if any), in which the main direct current when viewed from the converter unit dc terminals always flows in the same direction. A semiconductor converter section is supposed to be capable of operating as an independent unit but components such as fuses, reactors, snubbers, and/or heat sinks may be common to the two sections.

3.8.1 *Forward Section (of a Double Converter Unit)*

That portion of a semiconductor converter which operates in voltage-current quadrants 1 and 4 (Fig. 2).

3.8.2 *Reverse Section (of a Double Converter Unit)*

That portion of a semiconductor converter which operates in voltage-current quadrants 2 and 3 (Fig. 3).

3.9 Converter Transformer

Main transformer equipment of a semiconductor converter including one or more transformers or transformer windings used to provide the desired ac voltages and converter circuit configuration together with all the transformer auxiliary equipment.

3.10 Common Converter Transformer

Common transformer feeding two or more individual converter assemblies which may be individually or simultaneously energized through common or separate windings.

3.11 Equilibrium Temperature

Steady-state temperature reached by a component of a converter under specified conditions of load and cooling.

NOTE — The steady-state temperatures are in general different for different components. The times necessary to establish the steady-state are also different and proportional to the thermal time constants.

3.12 Rated Direct Current (I_{dN})

Mean value of the direct current specified by the manufacturer for the specified load and service conditions. It may be referred to as the base value to which other values of direct current are compared.

3.13 Rated Direct Voltage

Specified value at rated direct current of the direct voltage between the dc terminals of the assembly or equipment. This is the mean value of the dc voltage.

3.14 Rated ac Voltage

Rated rms value or the ac supply voltage at the supply terminals of the converter equipment, including the transformer if one is supplied. It may be referred to as the base value to which other values of ac supply voltage are compared.

3.15 Current Time Load Diagrams

Instantaneous record of load current with respect to time.

3.16 Uniform Load Duty

Duty for which a converter equipment carries a direct current of fixed value for an interval sufficiently long for the components of the converter to reach equilibrium temperatures corresponding to the said value of current. Figure 4 illustrates this kind of duty.

3.17 Intermittent Peak Load Duty

Type of duty for which loads of high magnitude and short duration are applied following non-load periods such that thermal equilibrium is reached between successive applications of load.

Figure 5 illustrates this type of duty.

3.18 Intermittent Load Duty

Type of duty for which intermittent loads are superimposed onto a constant base load such that thermal equilibrium is reached between successive applications of intermittent load.

Figure 6 illustrates this type of duty.

3.19 Repetitive Load Duty

Type of duty for which loads are cyclically variable such that thermal equilibrium is not reached within the cycle period.

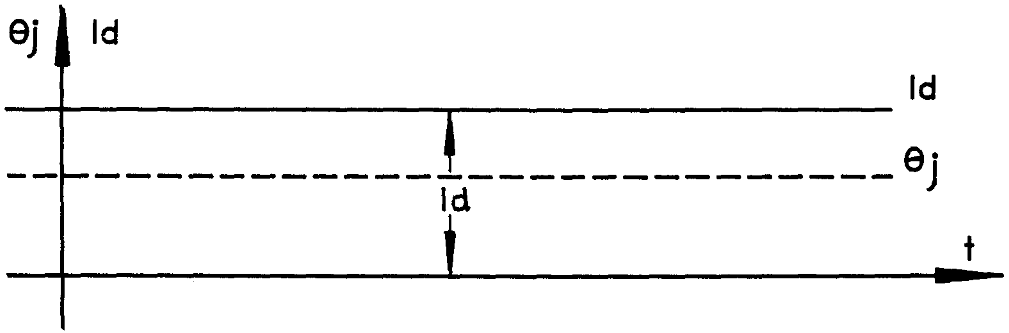

FIG. 4 TYPICAL CURRENT-TIME DIAGRAM FOR UNIFORM LOAD DUTY

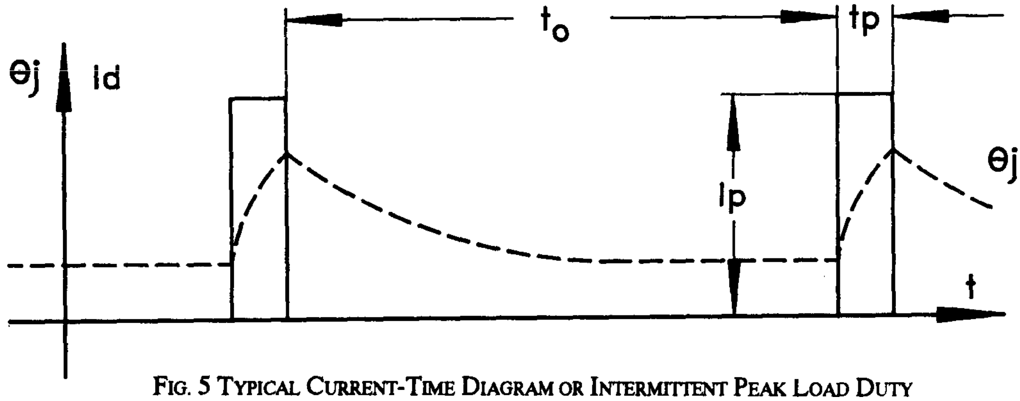

FIG. 5 TYPICAL CURRENT-TIME DIAGRAM OR INTERMITTENT PEAK LOAD DUTY

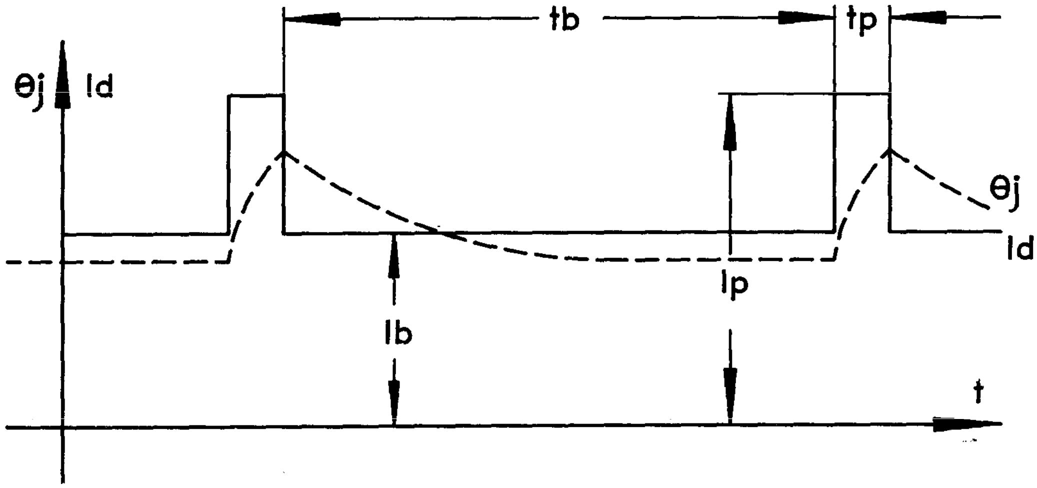

FIG. 6 TYPICAL CURRENT-TIME DIAGRAM FOR INTERMITTENT LOAD DUTY

Figure 7 illustrates this type of duty.

3.20 Non-repetitive Load Duty

Type of duty for which a peak load is applied by the end of a constant load period during which thermal equilibrium is reached.

Figure 8 Illustrates this type of duty.

4 RATED VALUES

4.1 General

The ratings defined in this clause are to be applied to complete semiconductor converter equipments, including such components as conductors, switchgear, reactors, and transformers as defined in 3.1.

The basis of the rating of a reversible converter shall be such that the converter operating either as a rectifier or as an inverter shall be capable of meeting all the specified load conditions, respectively.

Thermal time constants of semiconductors (including their cooling devices) are much shorter than those for converter transformers and drive motors. For this reason, the high short-time peak currents that occur in normal load duties of various types of adjustable speed dc motor drives are of greater significance for the semiconductor converter itself than for the converter transformers and motors.

The short-time peak currents tend to cause faster and relatively higher temperature rises in the semiconductor than in the transformers and motors.

For a semiconductor device the manufacturer's maximum junction temperature is the critical temperature above which loss of control or failure may occur.

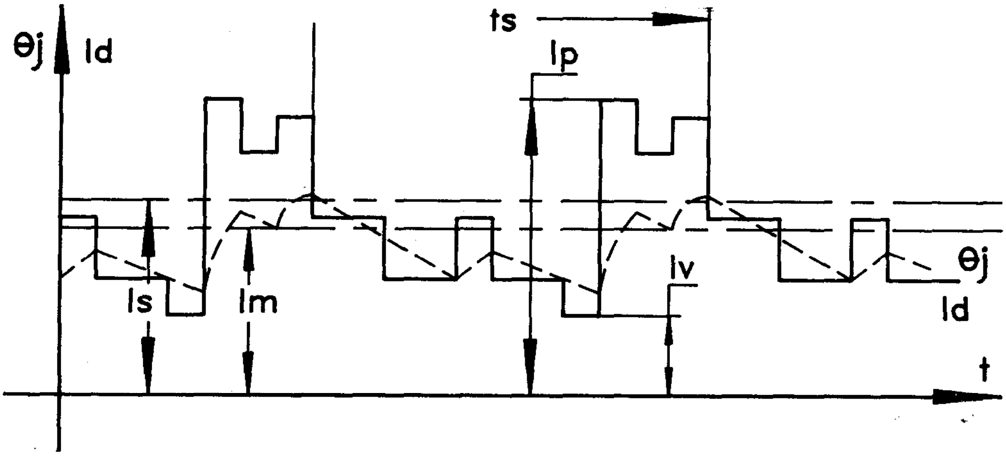

FIG. 7 TYPICAL CURRENT-TIME DIAGRAM FOR REPETITIVE LOAD DUTY

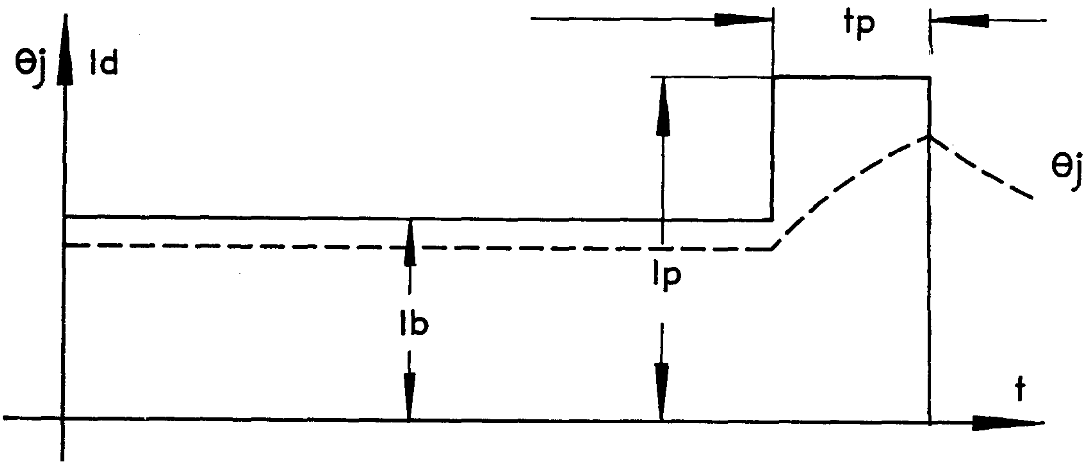

FIG. 8 TYPICAL CURRENT-TIME DIAGRAM FOR NON-REPETITIVE LOAD DUTY

Junction temperature cannot be measured directly but it may be accurately calculated for any load current-time diagram.

If load current-time diagrams can be specified by the user the manufacturer can calculate the junction temperature of the semiconductor to make certain that the maximum permissible junction temperature is not exceeded.

Table 1 List of Symbols

t_b = Base load interval

t_s = Load cycle period (duration)

t_o = No-load interval

t_p = Peak load duration

t = Time

I_b = Base load current value

I_p = Peak load current value

I_v = Minimum load current value for period t_s

I_m = Average load current value for period t_s

I_s = rms load current value for period t_s

I_{dN} = Rated direct current

I_d = Direct current output of converter section

θ_j = Temperature of the converter under consideration. This is usually taken to be the junction temperature of the semiconductor device

I_{PM} = The rated peak current for equivalent repetitive load duty.

I_{PMO} = The rated peak current for equivalent repetitive load duty with $I_v = 0$

r_N = A factor which is used to evaluate the per-unit average semiconductor junction power loss as a function of the per-unit direct current is given by:

$$r_N = \frac{R_o I_{dN}}{V_o}$$

where

R_o = Resistance value of the on-state characteristic of the semiconductor device, and

V_o = Threshold value of the on-state characteristic of the semiconductor device

A load current-time diagram can always be used as a basis for rating.

Two application classes are considered in this standard, one with converter loading conditions such that equilibrium temperature conditions are obtained between all superimposed loads and the other with cyclically variable loads such that thermal equilibrium is not reached within the cycle period.

The first application class is defined by the following types of duty:

a) Uniform Load Duty (Fig. 4),
b) Intermittent Peak Load Duty (Fig. 5), and
c) Intermittent Load Duty (Fig. 6),

A second application class is defined by the following types of duty:

d) Repetitive Load Duty (Fig. 7), ana
e) Non-repetitive Load Duty (Fig. 8).

To avoid ambiguity, it has been necessary to distinguish carefully between section ratings and equipment ratings. Consequently, all ratings except rated direct current I_{dN}, apply only to the semiconductor converter sections including such components as conductors, switchgears, reactors and transformers as defined in **3.8**. Note that some components may be common to more than one section and such components must be rated accordingly. This situation has no effect on the basis of rating which is equipment (system) rather than component orientated.

Rated direct current is applied to the converter equipment and is used as the per unit base for all of the ratings applied to the converter sections.

4.2 Rated Direct Voltage

The converter has to be designed for direct voltages higher than the rated direct voltage in order to meet the control requirements and allow an additional margin for regulation and ac line voltage variations. This results in a rated apparent power for the converter transformer that may greatly exceed the rated power of the converter assembly (*see* Note.)

Unless otherwise specified, the ideal no load voltage shall be calculated so as to satisfy the requirements of either **4.2.1** or **4.2.2** depending on whether the converter equipment is connected to a low voltage supply (1 000 V rms or less) or a medium voltage supply (1 000 V rms or more), respectively.

NOTE — For converters used for field excitations the converter is often designed for a multiple of the rated direct voltage in order to increase the rate of change of the field current during field current changes.

4.2.1 *Low Voltage Supplies,*

4.2.1.1 *Voltage limits for rated performance*

Rated converter performance shall be maintained when the steady-state fundamental line ac supply voltage is not less than 90 percent and not more than 110 percent of the rated value measured at the terminals of the converter equipment or the converter transformer, if included.

4.2.1.2 *Voltage limits for uninterrupted operation*

Uninterrupted operation of the converter shall be maintained even during inverter operation when the fundamental ac supply voltage is between 85 percent and 90 percent of the rated value.

But specified performance may not be attained.

4.2.2 *Medium Voltage Supplies*

4.2.2.1 *Voltage limits for rated performance*

Rated converter performance shall be maintained when the steady-state fundamental line ac supply voltage is not less than 95 percent and not more than 10 percent of the rated value measured at the terminals of the converter equipment or the converter transformer, if included.

4.2.2.2 *Voltage limits for uninterrupted operation*

Uninterrupted operation of the converter shall be maintained when the fundamental ac supply voltage exceeds 105 percent but is less than 110 percent or if this voltage is less than 95 percent but more than 90 percent of the rated value even under inverting conditions but specified performance may not be attained.

4.3 Rated Temperature Values

The maximum and the minimum limits of the ambient temperature or cooling medium temperature may be specified by the user or by the manufacturer in his tender. These temperatures shall preferably be specified in increments of 5°C.

If not otherwise specified, the semiconductor converter shall be capable of operation under the following conditions.

4.3.1 *Rated Temperature Values for Semiconductor Assemblies and Equipments*

4.3.1.1 *Ambient air temperature limits*

a) *Condition*	*Minimum*	*Maximum*	*TC 75 Class*
[1] Storage	-5°C	+45°C	1K3
[1] Transport	-40°C	+70°C	2K4
Air conditioned	+20°C	+30°C	3K1
Indoor	+5°C	+45°C	3K3
Outdoor	-25°C	+50°C	4K2

b) Daily average ambient air temperature is not to exceed 35°C.

c) Yearly average ambient air temperature is not to exceed 30°C.

NOTE — If storage at low temperatures may occur, precautions should be taken to avoid condensation of the moisture in the apparatus to prevent the risk of damage by the freezing of this moisture.

4.3.1.2 *Operational cooling fluid temperature limits including off-load periods*

Fluid	*Minimum*	*Maximum*
Air	+5°C	+45°C
Water	+5°C	+35°C
Oil	-5°C	+35°C

NOTE—The maximum temperature values specified are those referring to the cooling medium to be supplied by the user and not, for example, to circulating heat transfer agents included in the converter design.

4.3.2 *Rated Temperature Values for Converter Transformers*

Air-cooled outdoor equipment : The converter transformer shall be designed to operate in an ambient air temperature which does not exceed 45°C and does not average more than 35°C for any 24 h period and 30°C over the year.

Air-cooled indoor temperature : The converter transformer shall be designed to operate in an ambient air temperature of 45°C.

Water-cooled equipment : The converter transformer shall be designed to operate with incoming cooling water temperature which does not exceed 35°C and does not average more than 30°C for any 24 h period.

The allowable temperature rise of converter transformer windings as measured by resistance changes shall not exceed the following values:

	Liquid-Filled		*Dry-Type*	
Insulation class	105	120	155	220
Temperature rise (K)	50	60	75	145

1) Insulation class 120 designates thermally operated paper insulation with a permissible hottest spot temperature of 120°C.
2) Currents in excess of 1.0 per unit may only be applied on a load cycle basis such that the rms loading does not exceed transformer rating including consideration that one transformer may supply severe converters.
3) 'Converter transformers shall carry the ratings specified for the associated converter when loaded in accordance with the provisions of (2) above.

4.4 System of Establishing Rated Current Time Values for Semiconductor Assemblies and Equipment

All converters, whether or not they incorporate a transformer, shall be rated in terms of one of the following five duties:

1) Uniform load duty (Fig. 4),
2) Intermittent peak load duty (Fig. 5),
3) Intermittent load duty (Fig. 6),
4) Repetitive load duty (Fig. 7), and
5) Non-repetitive load duty (Fig. 8).

All rated current values are assigned for a specified duty. If a semiconductor assembly or equipment is designed to operate for different types of duty, separate current and time values shall be specified.

---

[1] The limits shown apply with the cooling fluid removed.

It should be noted that these ratings also apply to the equipment as a complete system committed to a specific application and not to any particular part of that system.

4.4.1 *Rated Current of a Common Converter Transformer*

A common transformer feeding two or more converter assemblies may be specified in terms of rated direct current even though the individual converters may be specified on an intermittent duty basis. In appropriate cases it may also be specified in terms of the basis of rating given in **4.5.1**, **4.5.2**, **4.5.3**, **4.5.4**, or **4.5.5**.

4.4.2 *Rated Values of a Double Converter*

Different rated values can be assigned to each section of a semiconductor double converter unit unless the duty of each section is the same.

The rated values of each section shall be in accordance with **4.5.1**, **4.5.2**, **4.5.3**, **4.5.4**, or **4.5.5**.

4.4.3 *Determination of Duty Type*

For adjustable speed dc motor drive applications, the load current diagrams are very often complex in variety of current magnitude, duration and repetition frequency. However, examination of the load current diagram will usually determine the most suitable type of load duty to be used as a basis for rated currents.

If the load duty changes, the effect of that change on all parts of the system should be checked. Adjustment of control and protective elements may also be required.

4.5 Rated Currents for Equipments and Sections

All current ratings apply over the entire specified direct voltage control range.

4.5.1 *Rated Currents for Uniform Load Duty*

The base load current value for this case is usually specified as the rated direct current ($I_b = I_{dN}$). Other base values are subject to agreement between the supplier and the user (*see* **3.16** and Fig. 4).

4.5.2 *Rated Currents for Intermittent Peak Load Duty*

Rated direct current is not applicable in this case. Intermittent peak load duty current ratings are subject to agreement between the supplier and the user. The duration (t_p) and magnitude (I_p) of the peak current and the minimum time (t_0) of no-load shall be specified (*see* **3.17** and Fig. 5).

4.5.3 *Rated Currents for Intermittent Load Duty*

The base load current for this case is usually specified as the rated direct current ($I_b = I_{dN}$). Intermittent load duty current ratings are subject to agreement between the supplier and the user.

The duration (t_p) and magnitude (I_p) of the peak current, the base load current (I_b) and the minimum time (t_b) of operation at the base load shall be specified. The duration (t_p) of the peak current (I_p) shall not be more than 5 percent of the duration (t_b) of the base load (I_b) (*see* **3.18** and Fig. 6).

Intermittent load duty can be specified by the same family of graphs shown in Fig. 11 for non-repetitive load duty with t_p denoting the duration of the intermittently applied load in this case.

4.5.4 *Rated Currents for Repetitive Load Duty*

The rated direct current of the converter equipment shall be specified as the rms value of the load current evaluated over the period of the load duty cycle in the worst case. It usually corresponds to the rated continuous current of the dc motor or motors supplied by the converter equipment. The load current is shared by the converter sections.

The rated direct current (1.0 p.u.) refers to the converter equipment and for a double converter it may exceed considerably the rms current rating of either section.

In addition to the rated direct current, there are two ways of defining ratings for repetitive load duty. The primary way is given in **4.5.4.1** and a secondary way in **4.5.4.2**.

4.5.4.1 *Load time diagrams for repetitive load duty*

The repetitive duty of a converter section should, when possible, be specified by the user in terms of one or more applicable current-time diagrams since this will result in the most economic design. These current-time diagrams then become part of the specifications between the user and the supplier and are, in effect, the current ratings of the converter section for repetitive load duty in the given application. In each case, the duration of the duty cycle (t_s), the peak value (I_p), the minimum value (I_v), the average value (I_m), and the rms value (I_s) of the load current evaluated over the period (t_s) of the duty cycle shall be specified for each converter section (Fig. 7 and Table 1).

NOTE — It is not necessary for load time diagrams to include allowances for abnormal conditions because the converter is otherwise designed to provide adequate protection for such conditions.

4.5.4.2 *Equivalent repetitive load duty rating*

I may not always be feasible for a user to specify detailed load-time diagrams for a given application but the need for a repetitive load duty rating may still exist. In such cases, the user need only specify values for I_p, I_s, I_m, I_v, and t_s as defined in Fig. 7 and Table 1 for the converter section. The basis for the rating then becomes the equivalent repetitive load-time diagram shown in Fig. 9 with I_p, I_v and t_s as specified and t_p given by:

$$t_p = \left(\frac{(I_m - I_v)\, I_{dN} + r_N\,(I_s^2 - I_v^2)}{(I_p - I_v)\, I_{dN} + r_N\,(I_p^2 - I_v^2)}\right) \cdot t_s$$

in which I_p, I_s, I_m, I_v and t_s correspond to the specified values and r_N is a semiconductor loss factor associated with I_{dN} as defined in Table 1.

The capability of the converter section to supply the equivalent repetitive load duty can be defined by the family of graphs shown in Fig. 10. Given a particular repetitive load duty and/or the associated values for I_p, I_s, I_m, I_v and t_s the value for the peak load duration t_p for the equivalent repetitive load duty can be calculated in accordance with the above relation (*see* Annex A) using the values of I_{dN} and r_N associated with the family of rating graphs for equivalent repetitive

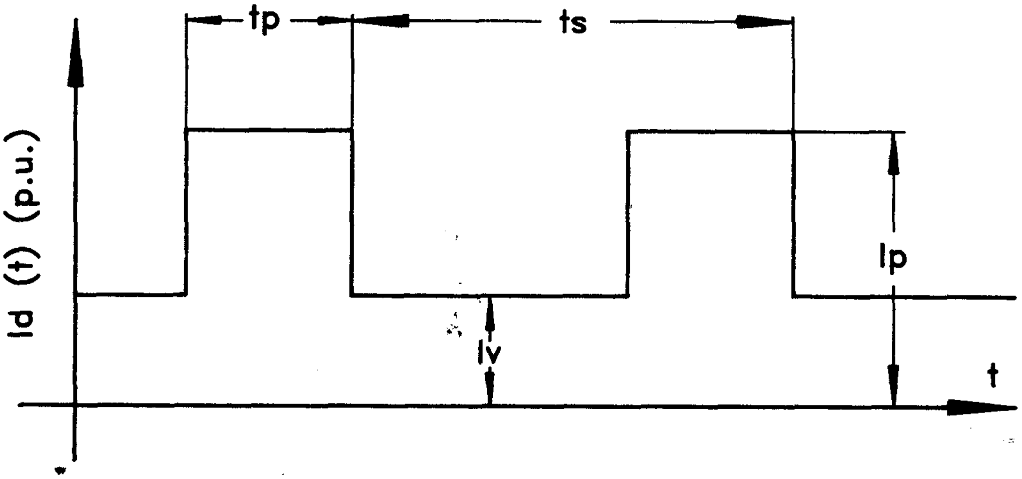

FIG. 9 EQUIVALENT REPETITIVE LOAD DUTY LOAD-TIME DIAGRAM

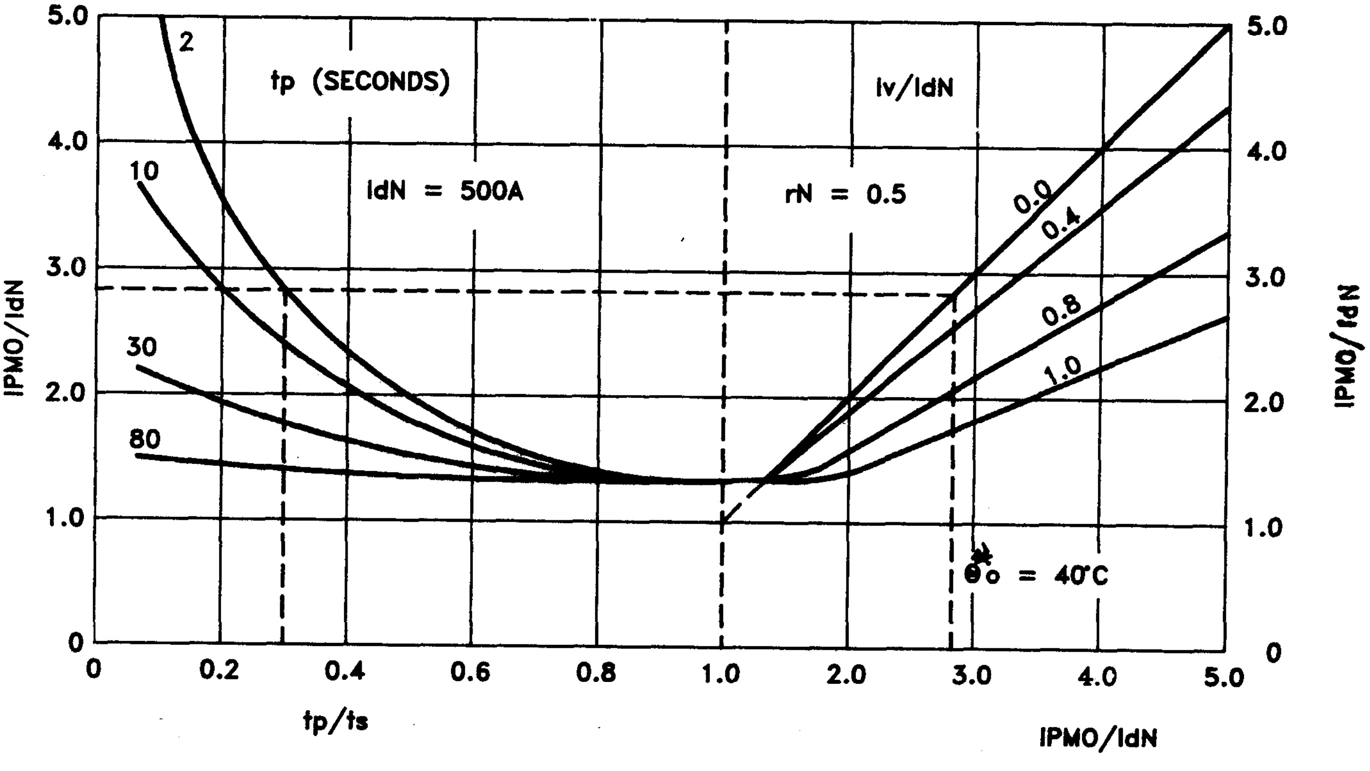

FIG. 10 TYPICAL RATING GRAPHS FOR EQUIVALENT REPETITIVE LOAD DUTY

load duty for the given converter as shown by the example in Fig. 10. The ratio t_p/t_s can then be calculated and the value for I_{PMO} corresponding to the calculated value for t_p can be obtained from the left-hand side of the rating graphs. With this value for I_{PMO}, the value for I_{PM} corresponding to the per unit value

$$\bar{I}_V = \frac{I_V}{I_{dN}}$$

calculated for the minimum current can be obtained from the right-hand side of the rating graphs. An example for this procedure is shown by the dotted lines in Fig. 10. Since $I_{PM} = I_{PMO}$ for $I_V = 0$, the entry for the abscissa on the right-hand side can be made by the projection shown. The given load duty is then within the rating of the given converter if the value for $I_{PM} = I_{PM}$ (p.u.). I_{dN} so obtained is more than the peak value I_p associated with that load duty as this assures that the rated junction temperature of the semiconductor devices will not be exceeded. If desired, a reference can be made to Annex B for a rationalization of this rating method.

NOTE — Either the equivalent repetitive load duty graphs with I_{dN} and r_N specified on one or more sets of values for I_p, I_s, I_m, I_V and t_s can be used as a rating for equivalent repetitive load duty.

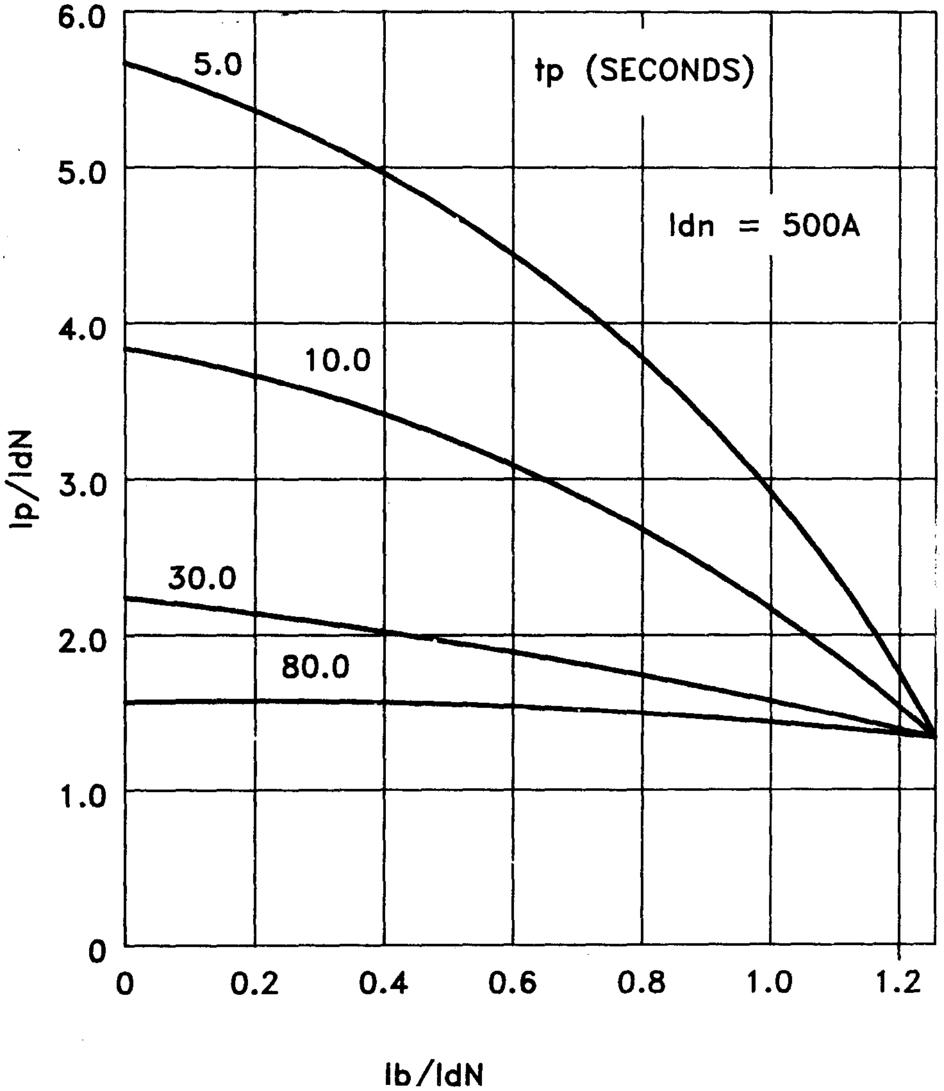

FIG. 11 TYPICAL RATING GRAPHS FOR NON-REPETITIVE LOAD DUTY

It is usual for the converter supplier to specify a maximum allowable value for I_p that corresponds to a current limit setting of the converter regulator and a maximum value or I_s that usually corresponds to I_{dN}. Such limits have precedence over those imposed to the equivalent repetitive load duty rating (*see* **4.5.4**).

4.5.5 *Rated Currents for Non-repetitive Load Duty*

The rated direct current for this duty is usually specified as the base load I_b. Non-repetitive load ratings are subject to agreement between the supplier and the user. (*see* **3.20** and Fig. 8).

This current rating can be specified by a family of graphs (I_p, I_b) for different values of peak load duration t_p as shown in Fig. 11. It is usually possible to define an equivalent non-repetitive load duty for other types of load duty as noted in **4.5.3**. For example, the equivalence is one to one for intermittent load duty.

Non-repetitive load duty can be used as a conservative approximation for repetitive duty if the values used for I_p and t_p in the non-repetitive case are the same as the values specified for the repetitive case and if the value used for I_b in the non-repetitive case is obtained from the relations.

$$I_b I_{dn} + r_N I_b^2 = I_m I_{dN} + r_N I_s^2$$

in which I_m and I_s are the mean and rms values respectively, specified for the repetitive case and r_N is the semiconductor loss factor in Table 1 and specified as a rating parameter in Fig. 10.

If this parameter is not known, a good approximation that may be used for I_b, conservative in most cases, is

$$I_b \approx \frac{2I_m + I_s}{3}$$

Because of such consideration, this rating is often used as a basis for establishing duty classes (**5**) or for testing the load duty capability of converter equipment (**6**).

4.6 Overload and Surge Current Capability

A semiconductor converter unit shall be capable of withstanding overload and surge currents of such magnitude and duration as is necessary to allow its protective equipment to operate as intended. The protection equipment shall permit the converter unit to carry any of the loads within its specified ratings.

NOTE — Equipment ratings may depend on more than just the junction temperature of the semiconductor devices. For example, mechanical fatigue of current limiting fuses caused by thermal fluctuations under varying load conditions could be a limiting factor and should be taken into consideration.

4.7 dc Power Rating (Converter Equipment)

The power rating of a converter equipment is the product of the rated direct current and the rated direct voltage of the converter unit.

4.8 Service Conditions

Service conditions are all external factors (ambient temperature, air humidity, character of ac source, etc) which may have an influence on the performance of a power converter. These are divided into two groups: Usual service conditions (**4.8.1**) and unusual service conditions (**4.8.2**).

4.8.1 *Usual Service Conditions*

Equipment conforming with this standard shall be capable of proper operation under the conditions specified in **4.8.1.1** to **4.8.1.4** except as noted therein. Exceptions to these provisions are considered to be unusual service conditions (**4.8.2**) the and require special agreements between the user and the supplier.

4.8.1.1 *ac Line voltage variations*

The waveform of the ac line voltages as measured at the terminals of the converter equipment or converter transformers, if included, with that equipment connected and in operation under any set of rated conditions including no load, shall satisfy the following requirements:

1) (a) *Low voltage sources*
   The ac fundamental component of the line voltage shall be not less than 90 percent and not greater than 110 percent of the rated value. Uninterrupted operation, however, shall be possible if this voltage is less than 90 percent but more than 85 percent even under inverting conditions although specified performance may not be achieved.

   (b) *Medium voltage sources*
   The ac fundamental component of the line voltage shall be not less than 95 percent and not greater than 105 percent of the rated values. Uninterrupted operation, however, shall be possible if this voltage exceeds 105 percent but is less than 110 percent or if this voltage is less than 95 percent but more than 90 percent even under inverting conditions although specified performance may not be achieved.
2) Repetitive instantaneous deviations of the ac line voltage from the simultaneous value of the fundamental component of the ac line voltage shall not exceed 25 percent of the crest value of the rated ac line voltage with the exception that deviations greater than 25 percent but less than 50 percent are permissible provided that the duration in each instance does not exceed 100 µs and that not more than two such instances occur in each cycle.
3) The negative sequence component of the ac fundamental line voltages shall not exceed 2 percent of the rated ac line voltage.
4) Non-repetitive transient overvoltage excursions of the ac line voltage waveform shall be limited to

a magnitude of twice the crest value of the rated ac voltage and a duration of 150 μs.

NOTES

1 These non-repetitive transient overvoltages may originate from the operation of circuit-breakers, atmospheric disturbances, or the switching of capacitor banks.

2 The converter transformer may be common but dedicated to several converter equipments.

3 ac line voltage variations and/or disturbances may be caused by other converters or equipment connected to the ac line as well as by the specified converter equipment being supplied in accordance with the provisions of this standard.

4.8.1.2 *ac Source impedance*

The ac source impedance is that defined at the input terminals of the converter equipment and is determined by the characteristics of the supply conductors, supply transformers, and other connected loads such as motors and capacitors.

4.8.1.2.1 *Minimum source impedance*

The minimum ac source impedance required for proper operation of the converter equipment shall be specified by the supplier. Additional impedance can be provided by series reactors and/or transformers if required.

NOTE — To ensure adequate equipment bracing and protective co-ordination, the maximum allowable ac system symmetrical short-circuit current at the input terminals of the converter equipment shall be specified by the supplier.

4.8.1.2.2 *Maximum source impedance*

The maximum ac source impedance required for proper operation of the converter equipment shall be specified by the supplier.

4.8.1.3 *ac Line frequency variation*

The deviation of the frequency of the line voltage from the rated value shall not exceed ± 1 percent.

4.8.1.4 *Altitude*

The specifications apply when the altitude does not exceed 1 000 m (3 300 feet).

4.8.2 *Unusual Service Conditions*

The use of semiconductors, power converter equipment, associated drive control, and drive equipment under conditions departing from those above shall be considered unusual.

Unusual conditions of the kind listed below may require special optional construction or protective features and where known or expected to exist shall be called to the attention of the manufacturer:

1) Exposure to damaging fumes;
2) Exposure to excessive moisture (relative humidity greater than 95 percent);
3) Exposure to excessive dust;
4) Exposure to abrasive dust;
5) Exposure to steam or condensation;
6) Exposure to oil vapour;
7) Exposure to explosive mixtures of dust or gases;
8) Exposure to salt air;
9) Exposure to abnormal vibration, shocks, or tilting;
10) Exposure to weather or dripping water;
11) Exposure to unusual transportation or storage conditions;
12) Exposure to extreme or sudden changes in temperature;
13) Unusual space limitations;
14) Unusual operating duty;
15) Unbalanced alternating-current voltages;
16) Unbalanced alternating-current system impedance;
17) Rectifier cooling water containing acid or impurities which may cause excessive scale, sludge, electrolysis, or corrosion of the rectifier parts exposed to the water;
18) Unusually strong magnetic fields;
19) Unusually high nuclear radiation;
20) Maximum room ambient of greater than 40°C or less than 0°C;
21) Altitudes exceeding 1 000 m; and
22) Unusually high levels of radio frequency interference (RFI) transmitters.

4.8.3 *Environmental Conditioning*

It is recognized that in various industries there are numerous different concentrations of gases, dust and dirt.

Consideration of equipment appearance and minimization of effects of adverse environments make it advisable to plan installations of electronic components to use the cleanest air readily available.

For example, avoid use of air originating directly from industrial processes which produce excessive dust and/or corrosive gas by-products (for example, blast furnaces, slag pits, pickle lines, paper machines, etc) and lead to the need for special and frequent maintenance schedules and the possibility of consequent outages .... Adherence to a clean environment to which electronic equipment is subjected will lead to an increased mean time between failures. Improved life and reliability will result if temperature is held between 20°C and 25°C.

4.8.4 *Storage of Equipment*

a) *General*

The equipment shall be placed under adequate cover immediately upon receipt as packing coverings are not generally suitable for out-of-doors or unprotected storage.

b) *Temperature and humidity*

Maintain storage temperature within specified temperature limits of -5°C to +45°C (**4.3.1**) and relative humidity within 5 percent to 95 percent.

Modules and panels shall be protected from condensation which might result from certain temperature/humidity cycles. If any part of the equipment is not to be installed immediately, it shall be stored in a clean, dry place and protected from variations in temperature, high humidity and dust.

If possible, sudden changes in temperature and humidity should be avoided. If the temperature of the storage room varies to such an extent that equipment surfaces are exposed to sweating or freezing conditions, it shall be protected by a safe, reliable heating system which will keep the temperature of the equipment slightly above that of the storage room. If the equipment has been exposed to low temperatures for an extended period of time, it should not be unpacked until it has reached room temperature; otherwise condensation will occur. The presence of moisture on certain internal parts can cause electrical failure of insulation, especially where high voltages are present.

c) *Water and dirt*

All equipment, except for that especially designed for outdoor service or storage, shall be protected from rain, snow, sleet, wind, dust, sand and hail.

d) *Corrosive materials*

All equipment shall be protected from salt spray, fungus, and other chemical and/or biological corrosive contaminants or agents.

e) *Altitude*

Equipment shall not be stored above 4 500 m (14 750 feet) above sea level.

f) *Storage time*

The above specification apply to shipping and storage durations of up to one year. Longer times may require additional special treatment.

5 DUTY CLASSES FOR NON-REPETITIVE LOAD DUTY

5.1 Non-repetitive load duty classes as given in Table 2 can be assigned when appropriate for adjustable speed electric drive system applications.

Table 2 gives rated current values for semiconductor converters in percent of rated direct current for non-repetitive load duty as defined in **4.5.5** and Fig. 8.

NOTE – If two sets of values are specified for any duty class, both apply.

6 TESTS FOR THYRISTOR ASSEMBLIES

6.1 All tests shall be conducted according to Annex C except for the temperature-rise test for which a converter intermittent load duty class cannot be applied or adapted.

6.2 In those cases, the temperature-rise test should be performed using an equivalent repetitive load duty (**4.5.4.2**) or an equivalent non-repetitive load duty (**4.5.5**).

Table 2 Duty Classes for Industrial Applications

Duty Class	I_b percent	I_p percent	t_p
IG	100	120	10 s
IIG	100	150	10 s
IIIG	100	150	60 s
IVG	100 100	150 200	60 s 10 s
VG	100 100	200 300	60 s 10 s

ANNEX A

(*Clause* 4.5.4.2)

CALCULATION METHOD FOR EQUIVALENT REPETITIVE LOAD DUTY GRAPHS

This annex has been added for clarification purposes.

Consider the equivalent repetitive load duty cycle shown in Fig. 9. The maximum junction temperature (θ_M) for this load duty is given by an equation having the form,

$$\theta_M = \theta_o + f(t_p, t_s) \cdot (Q_p - Q_v) + R_{JA}\, Q_v$$

where

θ_o = Temperature of the cooling medium,

R_{JA} = Steady-state thermal resistance between the semiconductor junction and the cooling medium of the associated heat sink,

Q_P = Junction heat loss produced by the current I_p, and

Q_v = Junction heat loss produced by the current I_V.

If the transient thermal impedance $c(t)$ of the cooling system were given by,

$$c(t) = R_{JA}\,(l - e^{-t/T}),$$

then the function $f(t_p, t_s)$ is given by,

$$f(t_p, t_s) = R_{JA}\,(l - e^{-t_p/T})/(l - e^{-t_s/T}).$$

Usually, however, the functional form is more complicated than this and numerical solutions are used. In such cases,

$$f(t_p, t_s) = \sum_{j=0}^{\infty} \left[c(t_p + jt_s) - c(jt_S) \right]$$

For the exponential case given above,

$$f(t_p\,, t_s) = \sum_{j=0}^{\infty} \left[R_{JA}\,(l - e^{(t_p + jt_S)/T}) - R_{JA}\,(l - e^{-jt_S/T}) \right]$$

a sufficient number of terms in the summation should be included to obtain an accuracy of ±0.5°C.

The maximum peak junction power loss Q_{PM} allowable for a given rated junction temperature θ^* and a maximum rated ambient cooling temperature θ_o^* is then given by,

$$Q_{PM} = \left[(\theta^* - \theta_o^*)/f(t_p, t_s) \right] + Q_V \left[l - R_{JA}/f(t_p, t_s) \right]$$

It will be convenient to define a rated continuous power loss Q^* by the expression,

$$Q^* = (\theta^* - \theta_o^*)/R_{JA}$$

Then,

$$\overline{Q}_{PM} = \overline{Q}_{PMO} - \overline{Q}_v\,(\overline{Q}_{PMO} - 1)$$

where

$$\overline{Q}_P = Q_P/Q^*$$
$$\overline{Q}_V = Q_V/Q^*$$
$$\overline{Q}_{PMO} = R_{JA}/f(t_p, t_s)$$

The above relation has a particularly simple form but it would be much more useful if it were expressed in terms of converter current rather than semiconductor power loss.

As shown in Fig. 12 the junction power loss Q is a function of converter current I, that is, $Q = Q(I)$, and is determined by the design of the converter equipment. The inverse function can be represented by

$$I = I(Q)$$

Thus, given values for t_p and t_s,

$$Q_{PMO} = R_{JA}/f(t_p, t_s)\, Q^*$$
$$I_{PMO} = I(Q_{PMO})$$
$$\overline{I}_{PMO} = I_{PMO}/I_{dN}$$

Using these relations, the graphs on the left-hand side of Fig.10 can be generated. Then, given I_{PMO} and I_v,

$$\overline{Q}_{PMO} = Q(I_{PMO})/Q^*$$
$$\overline{Q}_v = Q(I_v)/Q^*$$
$$Q_{PM} = [\overline{Q}_{PMO} - \overline{Q}_v\,(\overline{Q}_{PMO} - 1)]\, Q^*$$
$$\overline{I}_{PM} = I(Q_{PM})/I_{dN}$$

Using these relations, the graphs on the right-hand side of Fig. 10 can be generated.

In practice, it is usually more convenient and useful, particularly for the purpose of **4.5.4.2**, to approximate the power loss by means of a bounding quadratic expression having the form,

$$\overline{Q} = aI + bI^2$$

or

$$\overline{Q} = A(\overline{I} + r_N\,\overline{I}^2)$$

where

$$A = aI_{dN}/Q^*$$
$$r_N = bI_{dN}/a$$

or, equivalently in most cases,

$$r_N = R_o\, I_{dN}/V_o$$

where R_o and V_o have been defined in Table 1. It is somewhat more convenient to work directly with per unit values. The inverse function is then given by,

$$\overline{I} = \left[(1 + 4r_N\,\overline{Q}/A)^{1/2} - 1 \right] / 2r_N$$

The graphs of Fig. 9 and 10 should specify the per-unit base current I_{dN}, the power loss factor r_N, and the incoming temperature of the cooling fluid θ_0^x that are used in their construction.

Although $f(t_p, t_s)$, A, R_{JA} and θ^* are also required in that construction, these need not be known to the user for the system of ratings presented in this standard.

As an example, let

$$Q = 0.4\,I + 0.000\,4\,I^2$$

$$I_{dN} = 500A$$

$$f(t_p, t_s) = R_{JA}\,(l - e^{-t_p/T})/(l - e^{-t_s/T})$$

$$R_{JA} = 0.209\,23$$

$$T = 50.0\,s$$

$$\theta_0^* = 40°C$$

$$\theta^* = 125°C$$

Then

$$r_N = 0.5$$

$$Q^* = 406.25\ W$$

$$A = 0.492\,31$$

$$\overline{Q} = 0.492\,31\,(I\overline{J} + 0.5\,\overline{I}^2)$$

$$\overline{I} = \left[(l + 4.062\,48\,\overline{Q})^{1/2} - 1\right]$$

$$\overline{Q}_{PMO} = (1 - e^{-t_s/50})/(l - e^{-t_p/50})$$

$$\overline{I}_{PMO} = \left[(1 + 4.062\,48\,\overline{Q}_{PMO})^{1/2} - 1\right]$$

The family of graphs of this relation is shown on the left-hand side of Fig. 9 and 10.

For any given I_V,

$$\overline{Q}_v = 0.492\,31\,(\overline{I}_V + 0.5\,\overline{I}_v^2)$$

And for any given I_{PMO}

$$\overline{Q} = 0.492\,31(\overline{I} + 0.5\overline{I}^2)$$

It then follows that,

$$\overline{Q}_{PM} = \overline{Q}_{PMO} - \overline{Q}_V\,(\overline{Q}_{PMO} - 1)$$

$$\overline{I}_{PM} = \left[(l + 4.062\,48\,\overline{Q}_{PM})^{1/2} - 1\right]$$

The family of graphs of this relation is shown on the right-hand side of Fig. 9 and 10.

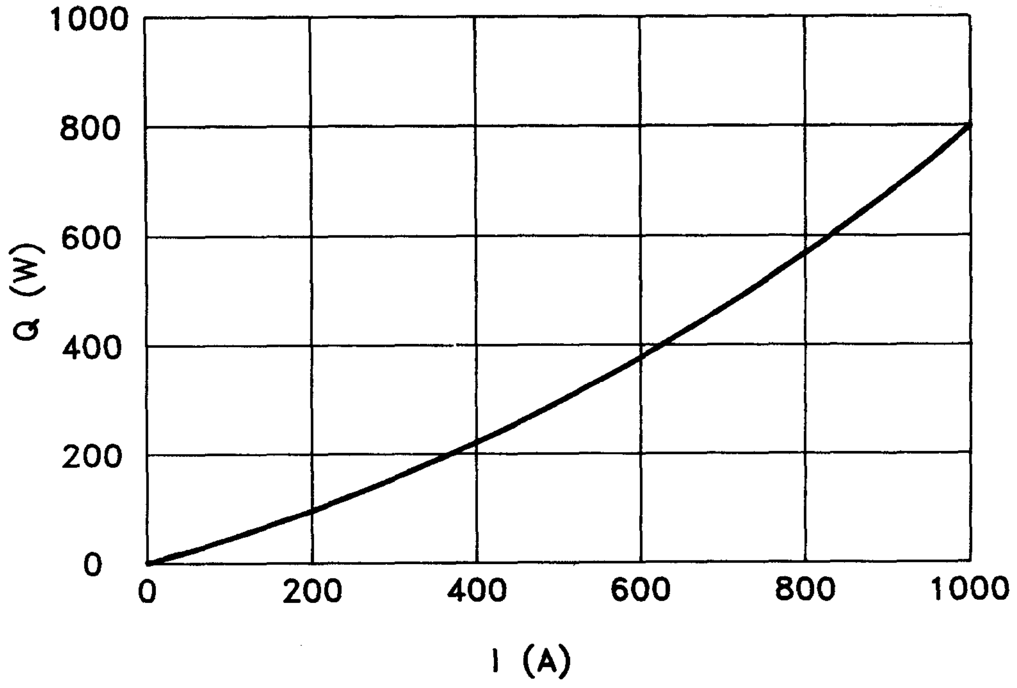

FIG. 12 FUNCTION HEAT LOSS IN FUNCTION OF THE CURRENT

ANNEX B

(*Clause* 4.5.4.2)

BASIS FOR THE EQUIVALENT REPETITIVE LOAD DUTY

This annex has been added for clarification purposes.

The purpose of the equivalent repetitive load duty rating is to provide a relatively simple means for a user to evaluate whether or not a given repetitive load duty cycle such as the one shown in Fig. 7 is within the capacity of the equipment supplied.

The equivalent repetitive load duty rating is based on the assertion that this evaluation can be based solely on two sets of data:

1) The calculated values for I_p, I_s, and I_M for the given load duty cycle as defined by,

$$I_p = Max\,[I_d(t)]$$
$$0 \le t \le t_s$$
$$I_m = \frac{1}{t_s}\int_0^{t_s} I_d(t)dt$$
$$I_S = \left[\frac{1}{t_s}\int_0^{t_s} I_d^2(t)dt\right]^{1/2}$$
$$I_v = Min\,[I_d(t)]\ 0 \le t \le t_s$$

where, by the repetitive nature of the duty cycle having period t_s,

$$I_d(t + t_s) = I_d(t)$$

2) The capacity of the converter as defined by a family of graphs such as the one shown in Fig. 10 for an equivalent load duty as defined in **4.5.4.2**.

This Annex provides a basis for the validity of the above assertion.

Consider the junction heat loss $Q_1(t)$ for some given duty cycle as shown in Fig. 13. For this duty cycle,

Q_v = 20 W (minimum value)
Q_p = 200 W (peak value)
Q_m = 98 W (mean value)
Q_s = 114 W (rms value)
t_s = 10 s (cycle period)

The thermal system is assumed to be linear so that the principle of superposition can be applied. Furthermore, it is assumed that the unit thermal impulse response $h(t)$ of the junction temperature is a monotonically decreasing function of time, that is the junction temperature 'θ' (t) is the hot spot of the thermal system. Since the unit thermal step response $c(t)$ is the integral of the impulse response that is:

$$c(t) = \int_0^t h(\lambda)d\lambda,$$

the step response $c(t)$ is a concave function of time. By definition, this implies that,

$$c[(l-a)t_1 + at_2] \ge (l-a)\,c(t_1) + ac(t_2)$$

where

$$0 \le t_1 < t_2 < \infty \text{ and } 0 \le a \le 1$$

The duty cycle shown in Fig. 13 consists of a sequence of blocks as shown in Fig. 13A. The variable $\Delta\theta_j(t)$ represents the contribution of the jth block of junction power loss, in one particular cycle, to the total junction temperature $\theta(t)$ for any time $t > t_j$. In particular, for $t \ge t_{j+1}$

$$\Delta\theta_j(t) = Q_j\,[c(t - t_j) - c(t - t_{j+1})]$$

Because $h(t)$ is a positive, monotonically decreasing function, it follows for $a \ge O, b \ge O$, that, $c(a) \ge c(a + b) - c(b)$.

Thus, for $a = t_{j+1} - t_j$, $b = t_n - t_{j+1}$

$$c(t_{j+1} - t_j) \ge c(t_n - t_j) - c(t_n - t_{j+1})$$

and hence, for $j \le n - 1$

$$\Delta\theta_j(t_{j+1}) \ge \Delta\theta_j(t)_n$$

as indicated in Fig. 13A. Strict inequality holds for $j < n - 1$.

The total contribution $\Delta\theta(t)$ of all n power loss blocks in one particular cycle of the repetitive load duty to the total junction temperature $\theta(t)$ is given by the summation,

$$\Delta\theta(t) = \sum_{j=0}^{n-1} \Delta\theta_j(t)$$

It can be assumed, without loss of generality, that the time increments $\Delta t_j = t_{j+1} - t_j = \Delta t$ are uniform for $\theta \le j \le n - 1$ since the Q_j need not be distinct.

Consider the relative incremental contributions of the ith and jth power loss blocks to $\Delta\theta(t)$ as shown in Fig. 13B.

It $t_j > t_i$, then it follows, again as a result of the characteristic of the thermal impulse response $h(t)$, that,

$$c(t_n - t_j) - c(t_n - t_{j+1}) > c(t_n - t_i) - c(t_n - t_{j+1})$$

and hence, if $Q_j \ge Q_i$ that $\Delta\theta_j(t_n) > \Delta\theta_i(t_n)$

Conversely, if $Q_j < Q_i$, a new thermal duty cycle $Q'(t)$ could be created by exchanging power loss blocks *(i)* and *(j)* with the result that $\Delta\theta'(t_n) > \Delta\theta(t_n)$ where $\Delta\theta'(t_n)$ is the incremental junction temperature rise of the altered thermal duty cycle. The mean (Q'_M), rms (Q'_s), peak (Q'_p), valley (Q'_v), and period (t'_s) values for the exchange process can be repeated in such a way that the thermal duty cycle shown in Fig. 13C is created.

Clearly, $\Delta\theta'(t_n) > \Delta\theta(t_n)$.

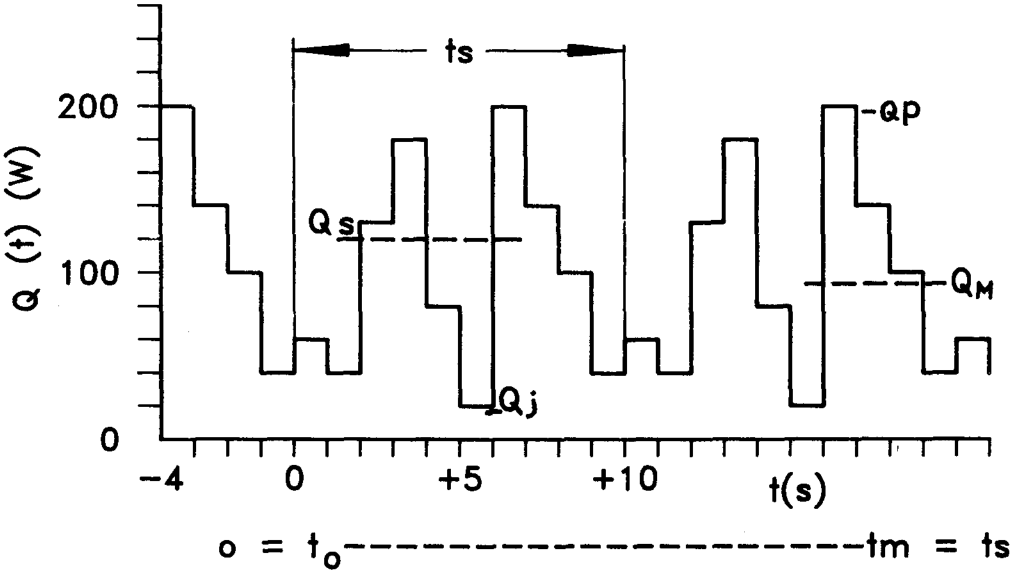

FIG. 13 JUNCTION HEAT LOSS TIME DIAGRAM FOR REPETITIVE LOAD DUTY

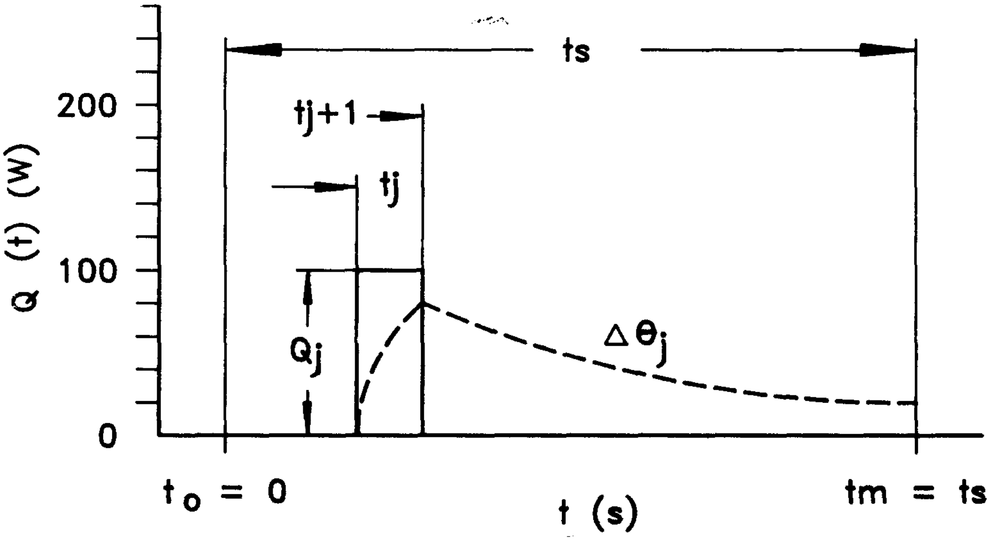

FIG. 13A

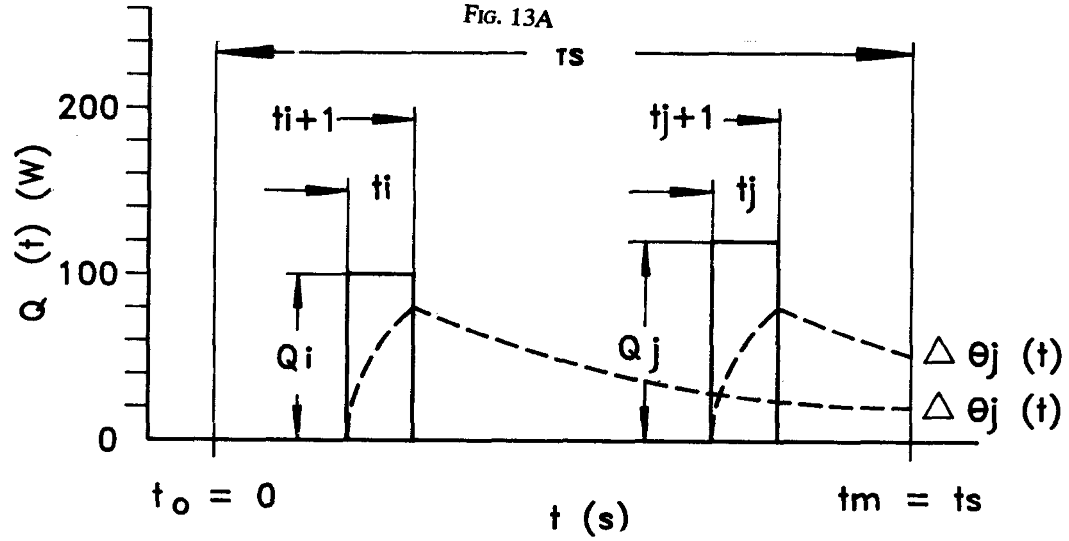

FIG. 13B

Furthermore, any subsequent exchange would involve a decrease in the incremental junction temperature rise. This result is independent of the choice made for the time origin of the duty cycle. The maximum junction temperature $\theta'(t)$ of the transformed duty cycle thus occurs at $t = t_n$, and it will be equal to or greater than the maximum junction temperature of the original duty cycle without regard for the instant within that duty cycle period at which it occurs.

In the following, attention will be focused on thermal duty cycles having the form shown in Fig. 13C with $Q_V = Q_o < Q_1 < \dots\dots < Q_{n-1} = Q_P$. It will be convenient to consider only the power loss $Q'(t)$ above the base load. Thus,

$$Q = Q'_o < Q'_1 < \dots\dots Q'_{n-1} = Q'_p$$

$$Q'_j = Q_j - Q_v$$

$$Q'_p = Q_p - Q_v$$

The contribution $\Delta\theta'(t_n)$ of the power loss blocks Q'_j above base load for $o \le j \le n-1$ to the total junction temperature at $t = t_s$ is given by,

$$\Delta\theta'(t_s) = \sum_{j=0}^{n-1} Q'_j \left[c(t_n - t_j) - c(t_n - t_{j+1})\right]$$

The mean value of the off-set power loss blocks is given by,

$$Q'_M = \frac{1}{t_s} \sum_{j=0}^{n-1} Q'_j \,(t_{j+1} - t_j)$$

An equivalent power loss duty cycle $Q_e(t)$ is now defined as shown in Fig. 13D where $t_p = Q'_M\, t_s/Q'_p$ and Q'_M, t_s, and Q'_p are defined as above.

Thus,

$$t_p = \sum_{j=0}^{n-1} (Q'_j/Q'_p)\,(t_{j+1} - t_j)$$

The contribution of the power loss Q'_p over the interval $(t_n - t_p \le t \le t_n)$ to the junction temperature at $t = t_s$ is given by,

$$\Delta\theta'_e(t_s) = Q'_p\, c(t_p)$$

By rearrangement of the summation appearing in the definition given above for t_p,

$$\Delta\theta'_e(t_s) = Q'_p\, c\left(\sum_{j=1}^{m} y_j x_j\right)$$

where

$$x_j = t_n - t_j$$

$$y_j = (Q_j - Q'_{j-1})/Q'_p$$

$$m = n - 1$$

In a similar manner, through a rearrangement of the summation involved

$$\Delta\theta'(t_s) = Q'_p \sum_{j=1}^{m} y_j\, c(x_j)$$

Using induction, it follows directly from the definition of a concave function previously given that,

$$\sum_{j=1}^{m} y_j\, c(x_j) \le \sum_{j=1}^{m} y_j\, x_j,$$

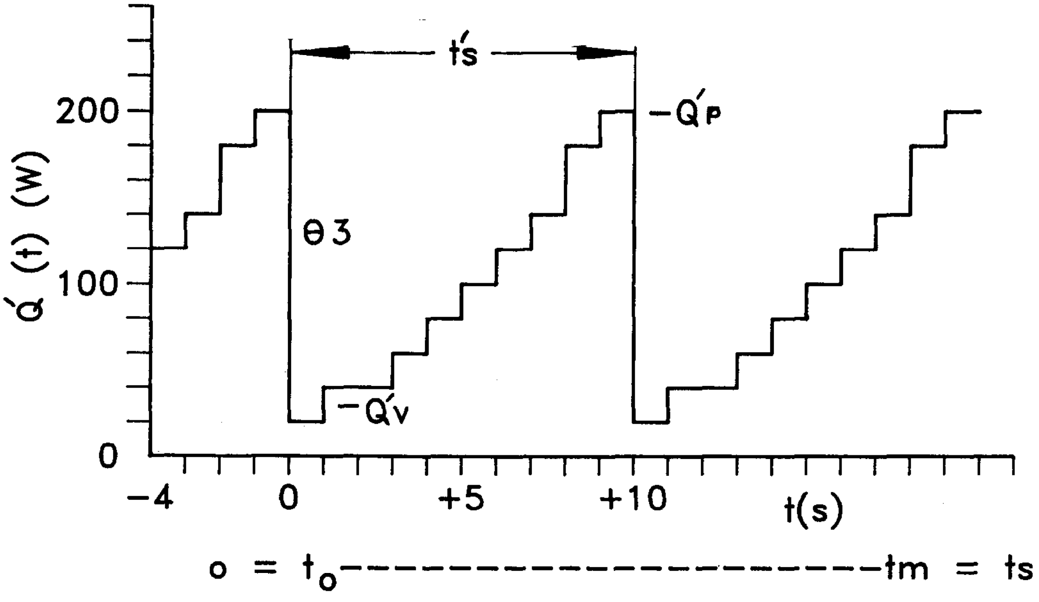

FIG. 13C

since

$$\sum_{j=1}^{m} y_j = 1$$

Therefore, $\Delta\theta'_e(t_s) \geq \Delta\theta'(t_s)$

It then follows that a specified repetitive load duty can be safely applied to a given converter section if the equivalent repetitive load duty is within the rating of the converter.

This determination requires a conversion from converter direct current to junction power loss.

Since the junction power loss $Q_d(t)$ can be bounded by a quadratic function of the direct current of the converter section (I_d), it can be assumed that,

$$Q_d(t) = aI_d(t) + b\,I_d^2(t)$$

where (a) and (b) are fixed parameters. (*see* Annex A).

Then for repetitive duty,

$$Q_M = \frac{1}{t_s}\int_0^{t_s}\left[aI_d(t) + b\,I_d^2(t)\right]dt$$

$$\text{or } Q_M = a\,I_M + b\,I_s^2$$

In the same way $Q_v = a\,I_v + b\,I_v^2$

$$Q_p = a\,I_p + b\,I_p^2$$

where I_v and I_p are defined in Fig. 7 and Table 1. Thus,

$$Q'_M = a(I_M - I_v) + b\,(I_s^2 - I_v^2)$$

$$Q'_p = a(I_p - I_v) + b(I_p^2 - I_v^2)$$

and hence,

$$t_p = \left(\frac{(I_m - I_v)\,I_{dN} + r_N\,(I_s^2 - I_v^2)}{(I_P - I_v)\,I_{dN} + r_N\,(I_p^2 - I_v^2)}\right) \cdot t_s$$

where the constant r_N is given by,

$$r_N = b\,I_{dN}/a$$

As given in Annex A, the parameter r_N would be given by the converter supplier.

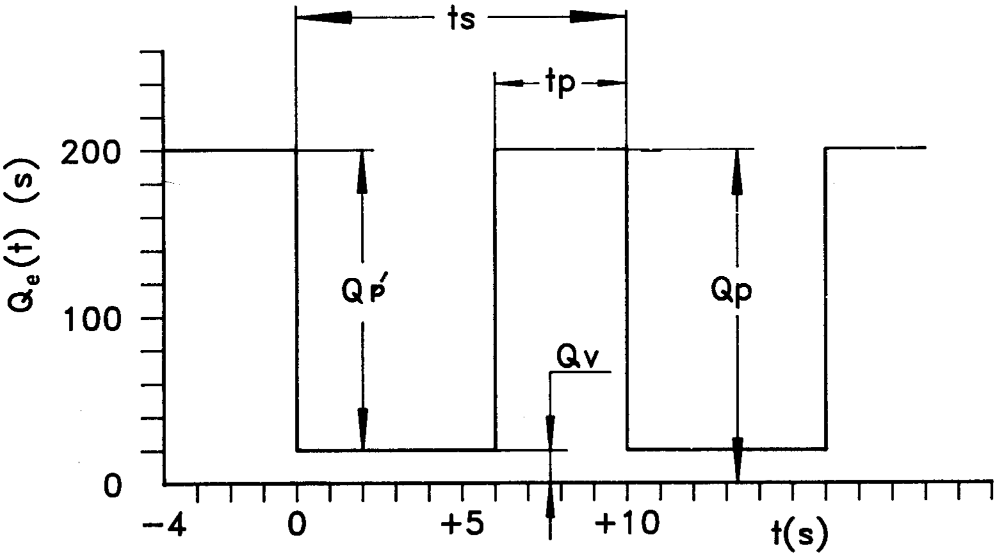

FIG. 13D

ANNEX C

(*Clause* 8.1)

TESTS FOR THYRISTOR ASSEMBLIES AND THYRISTOR CONVERTER EQUIPMENTS

C-1 GENERAL

All semiconductor devices and other components of the thyristor assembly shall be routine tested before the assembly into a converter.

All converters shall be routine tested before delivery unless otherwise agreed before the order.

Type tests shall be carried out to verify that the product will meet the requirements of these tests.

The tests shall be performed in electrical conditions equivalent to those in real service. If this is not practicable, the assemblies and equipments respectively have to be tested under those conditions which allow the specified performance to be proved.

In equipment tests, the assembly and other items of the equipment may be tested separately if this is more convenient. When tested separately, the stack or assembly shall be supplied from a transformer with a connection equivalent to that specified for the contact.

Unless otherwise agreed at the time of making the contract, the ac supply and test voltages should be of rated frequency except for the insulation test, which may be of any convenient frequency (at the manufacturer's choice) between 15 Hz and 100 Hz.

The tests shall unless otherwise agreed comprise all the following items except load test (**C-2.7**) and checking of properties under unusual service conditions (**C-2.10**) which are optional type tests (*x*) to be made only if specifically agreed in the contract.

C-2 TEST SPECIFICATIONS

C-2.1 Insulation Tests

C-2.1.1 *General*

Insulation tests are carried out to verify the correct state of insulation of a completely assembled unit. In general, they shall be carried out at the end of the tests. The auxiliaries, if any, the insulating test voltage of which is lower than the voltage specified in **C-2.1.4** shall be disconnected during the insulation test, this may apply, for example, to motors or fans and to measuring instruments. This does not apply, however, to auxiliaries for which, in case of an insulation fault, voltage may pass on to accessible parts not connected to the housing or from the side of higher voltage to the side of lower voltage. These are, for example auxiliary transformers, transductors, pulse transformers and instrument transformers, the insulation stress of which is equal to the parts of the main circuit.

The main terminals of the converter assemblies, as well as the anode, cathode and gate terminals of all semiconductor devices, shall be connected with each other.

Switchgear and controlgear in main circuits shall be closed or bridged. Auxiliaries not metallically connected to main circuits (for example system control equipment motors of fans) shall be connected with the housing during the insulation test according to **C-2.1.3** (a) and (b). During the insulation tests, units with housings consisting of insulating material shall be covered with metal foil. The foil is regarded as housing when performing these tests.

If in case of big housings a complete covering of the housing with a metal foil is not possible, a partial covering shall be applied at those spots which are supposed to be endangered.

	Type Test	*Routine Test*	*Clause Reference*
Insulation test	x	x	C-2.1
Light-load test	x	x	C-2.2
Current test	x		C-2.3
Checking of auxiliary devices	x	x	C-2.4
Power loss determination	x		C-2.5
Temperature rise test	x		C-2.6
Load test	(x)		C-2.7
Checking properties of trigger equipment	x	x	C-2.8
Checking co-ordination of protective devices	x	x	C-2.9
Checking properties under unusual service conditions	(x)		C- 2.10
Checking properties of incorporated stabilization means	x	x	C- 2.11

The test voltage with the rated frequency, but not exceeding 100 Hz, is applied according to C-2.1.2. The test voltage shall be increased to the full value in not less than 10 seconds continuously, or in maximum steps of 5 percent of the full value, starting at a maximum of 50 percent of the full value. The unit on test shall withstand the specified test voltage for one minute. The test has failed if a breakdown or a flashover occurs.

If an alternating test voltage cannot be applied due to components reducing the RFI level which cannot easily be disconnected, a direct test voltage may be used having the same value as the crest value of the test voltage given by the formula in C-2.1.4.

C-2.1.2 *Insulation Test of Converter Equipments with Parts Installed Separately*

All equipment parts are to be tested before delivery according to the recommendations concerned. The complete converter equipment shall be tested only with reference to the insulation of the connections (for example by measuring the installation resistance).

C-2.1.3 *Insulation Tests of Convertor Equipments Arranged in a Single Housing*

a) Insulation test of the components, metallically connected to the assembly, against the housing as well as against the line side of a converter transformer with separate windings, if any. Here the test voltage, in accordance with C-2.1.4 (a), is applied between the housing and the dc terminals connected with each other. The line-side terminals of a converter transformer with separate windings, if any, shall be connected with each other and with the housing.

b) Insulation test of the components, metallically connected to the line side against the housing, if a converter transformer with separate windings is used. Here the test voltage, in accordance with C-2.1.4 (b), is applied between the housing and the line-side terminals connected with each other. The dc terminals shall be connected with each other and with the housing.

c) Insulation test of the auxiliaires not metallically connected to the line side or the converter assembly (for example system control equipment, motors of fans). Here the test voltage, in accordance with C-2.1.4 (c) is applied between the housing and the terminals of the auxiliaries connected with each other.

C-2.1.4 *Test Voltages*

a) The test according to C-2.1.3 (a) is performed with a test voltage with an r.m.s. value of:

$$U_p = 2\frac{U_m}{\sqrt{2}} + 1\,000\ V$$

but at least 2 000 V, where U_m is the highest crest voltage to be expected between any pair of terminals. If the voltage to ground may be higher than between two terminals (for example with series connection of converter equipments), this higher voltage is to be applied. If the quotient

$$\frac{U_m}{2}$$

does not exceed 90 V, the test voltage may be reduced to 1 000 V.

For converters, the rated direct voltage of which is higher than 1 000 V, a test voltage lower than that specified by the formula may be agreed with.

b) The test, according to C-2.1.3 (b) is performed with a test voltage corresponding to the repetition test for the converter transformer.

c) The test, according to C-2.1.3 (c) is performed with a test voltage corresponding to the repetition test for the applied auxiliary components in accordance with the relevant Indian Standards, wherever existing.

C-2.2 Light Load Test

The test is carried out to verify that the equipment is correctly connected and that its static control properties fulfil the requirements.

The equipment shall be connected to an a.c. supply with a voltage equal to the rated voltage plus the voltage variation specified.

During the test, the alternating voltage, the direct voltage, the alternating current and the direct current shall be measured. In addition, the control signal causing adjustment or stabilization, if any, shall be measured when varying the direct voltage over the entire range for which the converter is designed.

The function of the trigger equipment, if any and auxiliary devices shall be checked during the test. If series-connected semiconductor devices are used in the arms of the converter, the voltage division shall be checked.

C-2.3 Current Test

The test is carried out to verify that the equipment will operate satisfactorily at rated current.

The dc terminals shall be short-circuited and an alternating voltage of sufficient value to cause at least rated continuous direct current to flow shall be connected to the ac terminals of the converter.

During the test, the control equipment if any and auxiliaires have to be supplied separately with rated voltage.

By proper co-ordination of control, if any and applied alternating voltage, rated continuous current shall be caused to flow through the dc terminals and a check made of its proper operation. If parallel-connected devices are used in the arms, the current division shall be checked. This may be done by current measurements, by voltage drop measurements, for example at fuses, or by measurements of the temperature of the semiconductor devices at a reference point.

When it is more convenient, the current test may be replaced by a full-load test at rated alternating voltage.

C-2.4 Checking of Auxiliary Devices

The function of auxiliary devices such as contactors, pumps, fans, etc, shall be checked. If convenient, this can be done in conjunction with the light-load test.

C-2.5 Power Loss Determination

Losses in the converter assembly may be determined either by calculations based on characteristics that can be verified or by direct measurements.

If practicable, power loss measurements shall be made with the converter operating as a rectifier.

The convertor transformer or a test transformer may be used for the test, at the choice of the manufacturer. If the converter transformer is used, the power losses of the complete converter shall be measured.

If the transformer designed for the converter is not used, the transformer used shall have the pulse and commutation number for which the converter is designed. In this case, only the losses in the thyristor assembly and in the trigger equipment will be measured during the power loss tests. The transformer losses have to be measured separately.

The power losses of the converter shall be measured during a light-load test and a short-circuit test. The total losses of the converter is the sum of the no-load losses and short-circuit losses calculated from these tests.

C-2.5.1 *Light-Load Power Loss Measurements*

If practicable, the test shall be carried out with the converter operating as a rectifier. The converter shall be connected to an ac supply with a voltage equal to the rated voltage and to resistive load on the dc side.

The test shall be carried out at the direct voltage for which the efficiency is to be determined (adjusted by phase control) and with a current through the converter not lower than is necessary to avoid the light-load voltage rise of the converter.

The input ac power to the converter shall be measured, including all trigger equipment and auxiliaries, the losses of which are to be included when calculating the efficiency and whose losses are not significantly dependent upon the load of the converter.

The output power is to be measured by a wattmeter. The light-load power losses are equal to the input ac power minus the output power as so measured.

The no-load power losses are equal to the measured light-load power losses minus the power losses in the converter circuit because of load current, calculated from the measured direct current, the threshold voltages and measured resistances of the circuit (eddy current losses neglected).

C-2.5.2 *Short-Circuit Power Loss Measurements*

If practicable, the test shall be carried out with the converter operating as a rectifier in short-circuit. The short-circuit connection shall, if necessary, include an inductance chosen such that the ripple current superimposed on the direct current becomes about the same as is expected at those load conditions for which the efficiency is to be determined. Inclusion of a small resistance may also be necessary to ensure enough voltage for the thyristors to become conducting.

The test shall be carried out at the direct current for which the efficiency is to be determined and with such a combination of supply alternating voltage and phase control that the overlap during the test becomes about the same as the overlap anticipated at those load conditions for which the efficiency is to be determined.

During the test, the trigger equipment and auxiliaries have to be supplied separately with rated voltage and their losses are not included in the short-circuit losses.

The power losses of the convertor at short-circuit are equal to the power supplied from the ac supply at the short-circuit test, corrected for core losses in converter transformer, if existing, and the power losses in the short-circuit connections on the dc side, as determined from measurements of mean values of direct current and direct voltage.

If agreed between the user and the supplier or if the converter is not designed to operate under the conditions given above, the short-circuit power loss measurements shall be made at short-circuit and delay angle zero.

C-2.6 Temperature-Rise Test

The temperature-rise of the semiconductor devices shall be determined under the test conditions given for the current test and under rated cooling conditions least favourable.

The temperature rise shall be measured at a specified point and the result shall be used to verify the design intention of the cooling system.

The test shall be performed for several of the devices including those operating at highest temperature.

NOTE — This assumes that the losses in the semiconductor devices due to leakage currents are negligible.

C-2.7 Load Test

Load test shall be made only if specifically agreed in the contract, and may substitute the temperature rise test.

The test is to be performed in the same manner as the current test at low voltage (C-2.3). When necessary, the dc terminals are short-circuited over a smoothing reactor. The co-ordination of phase control, applied alternating voltage and the smoothing reactor if included shall be made so that the ripple current superimposed on the direct current corresponds as near as possible to those expected in service. All service conditions that may have influence on the test result including cooling conditions and altitude shall be identical with or equivalent to those specified for the rated current.

Direct current shall be applied with amplitudes, durations and load sequences as specified.

The temperature rise at a specified point on the semiconductor devices shall be recorded. The rise of virtual junction temperature shall be calculated based on the temperature measurements in order to show that the assembly is capable of supporting the specified load duty without exceeding maximum virtual junction temperature for the devices.

C-2.8 Checking the Properties of the Trigger Equipment

It is not feasible to try to verify the properties of the trigger equipment under all those load conditions which may prevail in real operation. However, it recommended that trigger equipment should be checked under real load conditions as far as possible. When this cannot be done on the manufacturer's premises, it can be performed after installation by agreement with the user.

When practicable, the checking of trigger equipment may be restricted to a check under two load conditions as specified in **C-2.2** and **C-2.3** respectively.

In either case the static and dynamic properties of the trigger equipment shall be checked. This shall include checking that the equipment operates satisfactorily for all values of supply voltages within the range of variation for which it is designed.

Due to the many possible variants of phase shifting circuits, it is not possible to state simple procedures for checking of the properties of the trigger equipments.

The dynamic properties may be checked by means of a similar test.

C-2.9 Checking the Co-ordination of Protective Devices

Checking the co-ordination of protective devices shall be done so far as is possible without stressing the components of the equipment above its rated overload currents.

Due to the wide variety of protective devices and their combinations, it is not possible to state any general rules for the checking of this co-ordination. However, if a system control equipment is designed to protect the converter from current overloads, its ability in this respect shall be checked.

C-2.9.1 Type tests to test the efficacy of fuse protection, if felt necessary, shall be agreed between the user and the supplier and the conditions specified.

C-2.9.2 Routine tests shall be performed to check the operation of protective devices. It is, however, not intended that the operation of devices such as fuses, etc; where the operation is based on destruction of the operating component, shall be checked.

C-2.10 Checking Properties Under Unusual Service Conditions

If the equipment is designed to operate under any unusual service conditions that have been specified, its ability to do so shall be checked if agreed at the time of making the contract. As a test of the complete equipment may cause unreasonable costs, a partial test (test of critical components) may be sufficient.

C-2.11 Checking Properties of Incorporated Stabilization Means

For those equipments in which means for stabilization of an output quantity (for example direct voltage, direct current) are included, the static and dynamic properties shall be checked. The test shall be performed to verify that the specifications are fulfilled.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act, 1986* to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any form without the prior permission in writing of BIS. This does not preclude the free use, in the course of implementing the standard, of necessary details, such as symbols and sizes, type or grade designations. Enquiries relating to copyright be addressed to the Director (Publications), BIS.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition.

This Indian Standard has been developed from Doc: No. ET 31 (3544).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 331 01 31, 331 13 75

Telegrams : Manaksanstha
(Common to all offices)

Regional Offices :		Telephone
Central :	Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	331 01 31 331 13 75
Eastern :	1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola CALCUTTA 700054	37 84 99, 37 85 61 37 86 26, 37 86 62
Northern :	SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43 60 20 25
Southern :	C. I. T. Campus, IV Cross Road, MADRAS 600113	235 02 16, 235 04 42 235 15 19, 235 23 15
Western :	Manakalaya, E9 MIDC, Marol, Andheri (East) BOMBAY 400093	832 92 95, 832 78 58 832 78 91, 832 78 92

Branches : AHMADABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. PATNA. THIRUVANANTHAPURAM.

Printed at New India Printing Press, Khurja, India